ANL 7616

ANL-7616

Argonne National Laboratory

THE COMPLETE (α, β, γ) PERSONNEL MONITOR

by

Richard W. Fergus

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Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.65

ANL-7616
Instruments

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Industrial Hygiene and Safety Division

October 1969

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ABSTRACT

A personnel hand and shoe monitor, PERCI (PERsonnel Contamination Instrumentation), has been developed to provide simultaneous detection of alpha, beta, and/or gamma contamination. Automatic operation provides uniform survey sensitivity that is independent of the user. Logic circuitry prevents incomplete surveys and causes "go" or "no-go" instructions to be flashed on an illuminated display panel.

Alpha, beta, and/or gamma events for each channel are detected with a large-area, gas-flow detector and pulse-separation circuitry. A unique background compensation feature implements statistical computation for each survey by comparing the actual number of events during the survey cycle with a number predicted from the background events preceding the cycle. Reliable operation with stable calibration is assured with solid-state circuitry and appropriate feedback.

Consistent performance with infrequent false alarms characterizes the operation of this monitor. Sensitivity has been demonstrated on many occasions when the monitor has detected contamination on the user that could not be located with conventional survey instruments.

INTRODUCTION

Many types of personnel monitors have been built in the past for various applications. A survey of the field installation at this Laboratory revealed that a monitor should have the following characteristics: (1) It must be easy to operate and provide simple instructions. (2) It must make quick, thorough, and dependable surveys. (3) It must be usable in high-background situations. (4) It should also be economical to fabricate, easy to maintain, and semiportable, and should have a pleasing appearance.

A personnel hand and shoe monitor, PERCI (PERsonnel Contamination Instrumentation), shown in Fig. 1, has been developed with characteristics of the "ideal" monitor. Not only reliable performance but also mechanical, economical, and aesthetic factors were considerations in the overall design.

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ABSTRACT

[illegible] monitor, [illegible] has been developed to provide [illegible] Auxiliary [illegible] at the [illegible] [illegible]

[illegible] counts for each channel [illegible] that the pulse [illegible] circuitry. A [illegible] computation [illegible] number of events during the survey [illegible] the background [illegible] calibration is assured with [illegible]

[illegible] characteristic [illegible] demonstrated [illegible] not [illegible]

INTRODUCTION

[illegible] types [illegible] have been built in the past for [illegible] survey [illegible] of this laboratory [illegible] characteristic [illegible]

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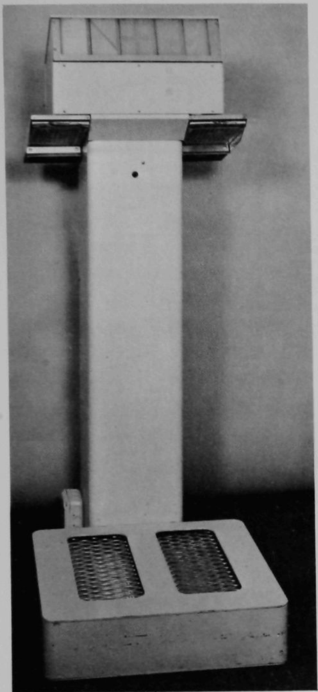


235-1411
Fig. 1. Photograph of PERCI

THEORY OF OPERATION

The monitor electronics consists of four detectors with associated circuitry, display logic, and common power supplies. Each monitoring channel (one for each extremity) is enabled independently during the survey cycle by switches mounted on the detectors. Large-area, gas-flow detectors with pulse-amplitude-separator preamplifiers provide two output circuits, one representing alpha-only events and the second representing all events. No attempt has been made to indicate the type or quantity of contamination that is detected. An alarm signal is generated if the alpha-only pulses counted during the survey cycle exceed a preset quantity. The other preamplifier output, containing pulses representing all events, is analyzed with a background-compensation technique. This technique involves predicting the number of events that should occur during the survey cycle from a count-rate measurement of background events occurring before the start of the cycle. A fixed quantity, representing the maximum expected statistical variation, is added to this predicted amount. If the actual number of events during the cycle exceeds this sum, an alarm signal is generated.

The functional diagram (Fig. 2) shows how the individual channels are assembled with logic circuitry to provide a simple master display of the survey cycle. The logic functions are implemented with a combination of transistor and relay circuitry in the Lamp Logic Module. A description of the display follows: The READY indicator will be extinguished when all detector switches have been operated. The WAIT indicator will then light until all channels have timed out. The HOT indications will be displayed immediately when sufficient counts have been accumulated to indicate an alarm condition. If a detector switch is released prematurely during a survey cycle, the INTERRUPT indicator will light and remain on until all remaining channels time out or all detector switches are released. The OK indication will be displayed after all channels finish an uninterrupted "no contamination detector" survey cycle. The OK or HOT indication will continue to be displayed until all detector switches are released. If a HOT indication is displayed, the READY indication will also be displayed after all channels time out.

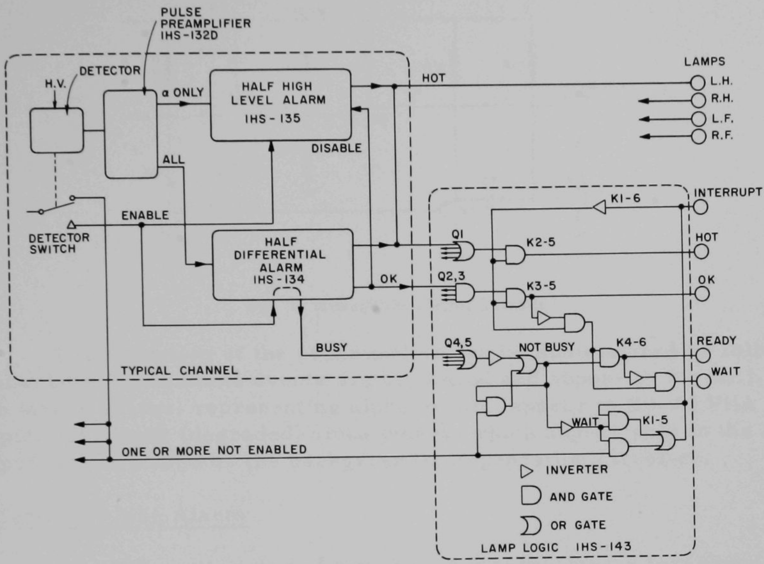


Fig. 2. Monitor Functional Diagram

CIRCUIT DESCRIPTION

Modular assemblies, which have been proven in other equipment, were used to supply the circuitry for this monitor. Most of the circuitry is of conventional design and does not require explanation. The pulse-separator preamplifier, differential-rise alarm, and high-level alarm will be described in detail. A complete set of monitor schematics is provided in the appendix.

Pulse-separator Preamplifier

The pulse-separator preamplifier consists of two complementary transistor feedback-amplifier stages, a biased amplifier, and two emitter-follower output stages. The first amplifier stage is operated with a current-sensitive input, the second as a feedback voltage amplifier. The output circuitry (shown in Fig. 3) illustrates the biased-amplifier or pulse-separation circuitry. Diode CR1 provides a biased-amplifier function. The back bias on this diode (about 4 V) determines the threshold for the amplifier. Pulses exceeding this bias are passed by the forward conduction of the diode to the emitter-follower output stage (transistor Q6). The low conduction resistance of CR1 also shunts resistor R11 during the large pulses. Since R11 is part of the feedback network of the voltage amplifier, the gain of this amplifier stage is reduced during large pulses.

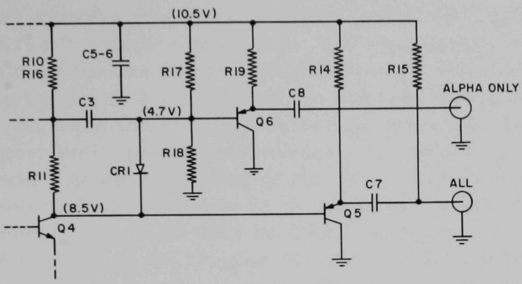


Fig. 3. Preamplifier Output Circuitry

The operation of the preamplifier can be summarized as follows: Alpha, beta, and gamma events are amplified and appear in the ALL output. The larger pulses, representing alpha events, appear in the ALPHA ONLY output. The weak (degraded) alpha pulses, which appear only in the ALL output, are analyzed by the background-compensation circuitry.

Differential-rise Alarm

The differential rise alarm circuit incorporates a background-compensation technique which predicts, from a conventional count-rate measurement, the number of events that should occur as a result of background during the survey cycle. The survey cycle is initiated by the person operating the detector switches. An allowance (sensitivity) for statistical variations is added to the predicted number, and, if the actual number exceeds this sum, an alarm signal is generated. A simplified functional diagram (Fig. 4) illustrates this technique. Components performing the switching functions are referenced to the complete schematic diagram (Fig. A.7 in the appendix).

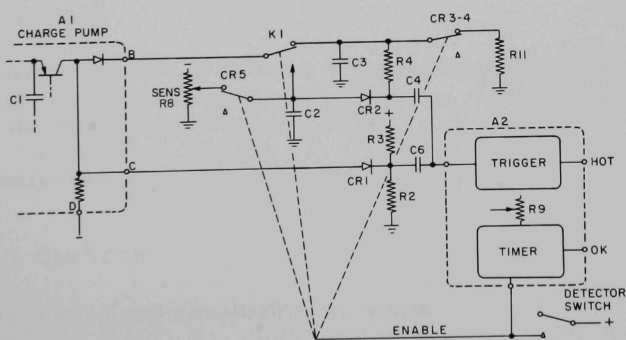


Fig. 4. Differential-rise Functional Diagram

Between surveys, the charge-pump circuit (A1) generates a fixed quantity of charge for each input pulse. The equilibrium voltage on capacitor C3 (when the discharge current through resistor R11 equals the charge pumped by A1) is a function of the average background level. During the survey cycle, when the detector switch is operated, the cathode of diode CR2 is positively biased to a voltage corresponding to the average background level. At the beginning of the cycle, the anode is negatively biased to a level that corresponds to the expected statistical variation (SENS adjustment). The total bias on CR2, which must be overcome to couple a pulse through to the trigger circuit, is the sum of the sensitivity and the background levels. Each input pulse during the survey cycle increases the charge on C2 by a constant voltage increment. Therefore, the total bias on CR2 determines the number of pulses required to pass a pulse through CR2.

A preset electronic timer (part of A2) has also been enabled during this cycle. If the timer runs out before a pulse is passed by CR2, an OK output signal is generated. Conversely, if CR2 passes a pulse first, a HOT output signal is generated. Inhibit circuitry prevents simultaneous outputs.

The circuit can be analyzed analytically as follows:

Let,

t = survey time in seconds,

Q = charge pumped by A1 per input event,

N = average background in events per second,

and

V = equilibrium voltage on C3.

Then

$$V = QN(R11). \tag{1}$$

A balance condition is obtained when the input pulse rate is periodic (no statistical error) therefore; the voltage change on C2 during the cycle would equal the equilibrium voltage on C3, or

$$\text{C2 incremental voltage per event} = Q/C2$$

and

$$V_{C_2} = QNt/(C2). \tag{2}$$

Equating Eqs. 1 and 2 and simplifying, we obtain

$$t = (R11)(C2).$$

After the circuit is initially adjusted for balance with the timer (R9) control, only the SENS adjustment need be changed to obtain required sensitivity.

Between arrivals [illegible] single-channel [illegible] (SCA) generates a dash [illegible] pulses. The continuous [illegible] on [illegible] capacitor C1 [illegible] current through resistor R15 equals [illegible] background [illegible] diode CR2 [illegible] voltage [illegible] the average [illegible] negatively [illegible] corresponds to the [illegible] statistical variations [illegible] bias on [illegible] must be overcome [illegible] each [illegible] of the capacitor [illegible] Each input [illegible] by a [illegible] Therefore [illegible] determines the number [illegible] to make a pulse [illegible]

A [illegible] of A2 [illegible] been enabled [illegible] before a pulse [illegible] CR2 [illegible] generated. [illegible] a pulse [illegible] generated [illegible] through [illegible]

The [illegible] analyzed [illegible] as follows:

Let

V = [illegible]

Q = [illegible] per input event

N = average background in events per [illegible]

and

V [illegible] as [illegible]

Then

[illegible]

[illegible] when the input pulse [illegible] the [illegible] C2 [illegible]

[illegible] $Q/C2$

[illegible]

[illegible] 2 [illegible]

[illegible]

[illegible]

A high-level alarm has been incorporated to prohibit false indications from an abnormally high background level. A discriminator is formed by CR1, R2, R3, and C6, which can also drive the alarm trigger circuit. Terminal C of the charge pump (A1) is at a negative potential between events. During the charge-pump operation, this terminal is clamped to the voltage at terminal B. Therefore, the peak pulse magnitude at terminal C is equal to the voltage on C3 between surveys and the voltage on C2 during the survey cycle. The discriminator level is preset to pass a pulse to the alarm trigger if this voltage exceeds the magnitude for linear circuit operation.

High-level Alarm

The High-level Alarm is used to generate the alarm signal if the number of input pulse during the survey cycle exceeds a preset number. Pulses from the ALPHA ONLY output of the preamplifier are coupled to the input of the charge pump (A1), as shown in Fig. 5. When the circuit is enabled (operation of the detector switch), CR1 is back-biased to remove the discharge path for C2. Each input pulse then increases the charge on C2 by a constant voltage increment. A discriminator is formed by CR2, R2, R3, and C3, as described in the discussion of the Differential-rise Alarm above. When the voltage on C2 exceeds the discriminator level, a pulse is passed to the trigger and an alarm signal is generated. The discriminator level determines the number of pulses required to alarm. This number is approximately equal to the ratio of the capacitance of C2 to that of C1. The A1 and A2 circuits are the same type as those used for the Differential-rise Alarm.

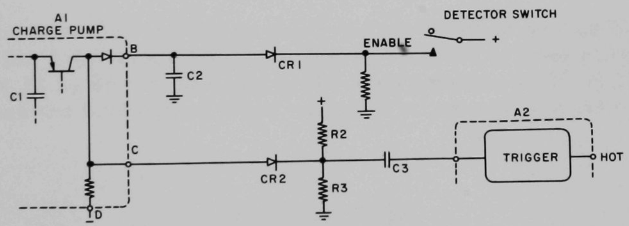


Fig. 5. Simplified High-level Alarm Circuit

HARDWARE CONSIDERATIONS

Several proposed installations dictated that the monitor be small and semiportable. Commercially available cabinets were not suitable. As a result, the cabinet shown in Fig. 6 was designed. Welding and sheet-metal fabrication methods have been used extensively.

The pedestal consists of three major pieces: a vertical member (which can house a gas cylinder), a flat bottom plate, and a shoe-detector

mounting flange. Teflon bearing blocks are mounted on the flange to support the detector carrier and grills. The shoe-detector mechanism was designed to allow the detector to drop to about 45° from horizontal when not in use so that dirt could fall or roll off the sensitive area of the detector. This feature is not used in the final version, although the assembly allows easy access to the detectors. The detector carriers are constructed from two pieces of angle welded to a tubing axle (same assembly for both shoes). An angle frame covered with expanded metal and welded to a tubing axle forms the step-on grill assembly.

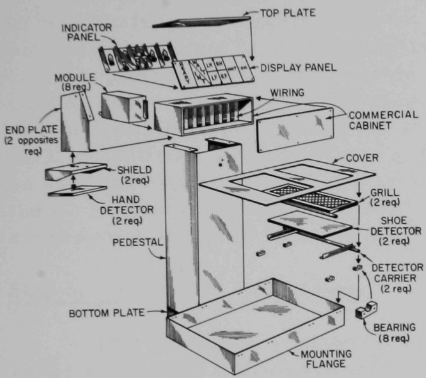


Fig. 6. Cabinet Layout

A commercial cabinet (available from Plug-In Instrument Company) is mounted on the top of the pedestal to house the electronic modules. End plates mounted to each end of the cabinet support the shield and hand detectors. An indicator panel assembly is mounted between the end plates. The display panel, consisting of a sandwich of clear plastic, instructions transparencies, transparent colored panels, and a translucent clear plastic, is mounted on the front of the end plates. A top cover completes the assembly of the cabinet.

The detectors are constructed from a standard design that has been in use at this Laboratory for many years. The active area of the hand detector is 12 by 26 cm, and that of the shoe detector is 12 by 36 cm. Each detector has ten 0.0254-mm-diam collector wires and a 0.0635-mm Mylar window.

CALIBRATION

The following steps have been found to be the most practical, although possibly not the most accurate, procedure for calibration of the monitor.

Step 1: Adjustment of the Balance (TIMER) of the Differential-rise Alarm

The balance of the Differential-rise Alarm can be adjusted either in the monitor or in a test setup that can supply proper voltages, indicators, and a pulse-generator signal. With the sensitivity adjusted for maximum (zero voltage on arm of SENS adjustment), a periodic input pulse rate of 500 to 1000 cpm is supplied to the input terminals. After the circuitry has reached equilibrium (no change in reading of meter connected to J1), the TIMER control is adjusted from maximum toward minimum cycle time until OK indications are obtained.

Step 2: Adjustment of the Preamplifier Pulse-separation Level

One Differential-rise Alarm module, which corresponds to the channel to be adjusted, is removed from this monitor. Both Differential-rise Alarm modules should not be removed at the same time, as the L. V. Power Supply may be "underloaded." With the H. V. adjusted to about 1400 V, a beta or gamma source is placed on the detector of the channel to be adjusted. The preamplifier gain is adjusted for slightly less gain than required to obtain HOT indications. Both low- and high-energy beta-gamma sources should be used for this adjustment. If sufficient preamplifier gain cannot be obtained, the H. V. should be increased slightly; if one or more preamplifiers has excessive gain, the H. V. should be decreased.

Step 3: Sensitivity Adjustment

For maximum sensitivity for an individual installation, the setting of the sensitivity (SENS) control is reduced until an acceptable percentage of false alarms is obtained. Sensitivity is related to the statistical variations of the background events, and therefore a particular sensitivity will be related to a certain percentage of false alarms. Where maximum sensitivity is not required, the SENS control can be preset. In one low-background location, experience has shown that the SENS control can be backed off 18 turns (25 turns maximum) from maximum sensitivity. The circuitry has proven to be stable, and presetting the control provided similar sensitivity on all units.

CONCLUSION

Four monitors have been in service for several years with satisfactory performance. At first, the "go/no-go" display was questioned. Many times, the monitors have detected contamination that could not be located with a portable instrument. Later, the same contamination would often be located on a sleeve or other areas of the user. These incidents have improved user confidence and acceptance of the monitor.

At the time of installation, the monitors were adjusted for high sensitivity with a cycle time of 7 sec. This adjustment proved to be too sensitive for practical operation. The cycle duration was changed to about 4 sec. Present sensitivity is: 500 and 1000 dis/min alpha for hand and shoe, respectively, and about 0.1 mR/hr beta-gamma for both hand and shoe.

The shoe detectors, which were originally designed to drop and allow dirt to roll off, have been fixed in the horizontal position. The detector surfaces are cleaned with a soft brush or battery-operated vacuum cleaner once a day. The expanded metal (0.120 in. thick) has

held up well and could probably be thinner. The grill assembly was designed for easy replacement of the expanded metal if it became necessary.

The modular electronics have also been used to modify commercial personnel monitors with equally good results. These installations use GM tubes in lieu of the gas-flow detectors for beta-gamma detection. Independent alpha channels are provided with air-proportional detectors and similar preamplifiers, but without pulse separation.

APPENDIX

Layout and Schematic Diagrams

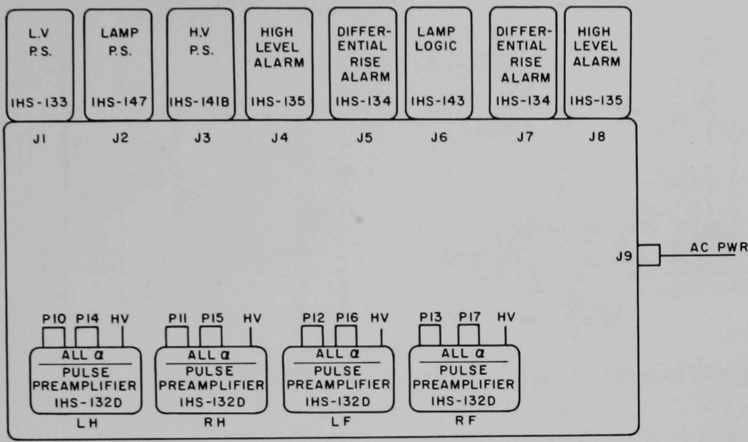


Fig. A.1. Layout of Personnel Monitor IHS-163

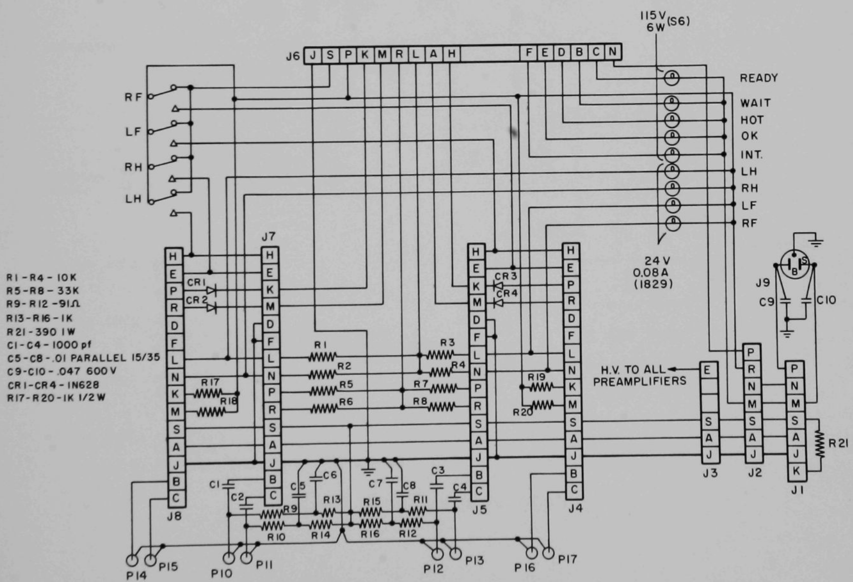


Fig. A.2. Cabinet Wiring for Personnel Monitor IHS-163

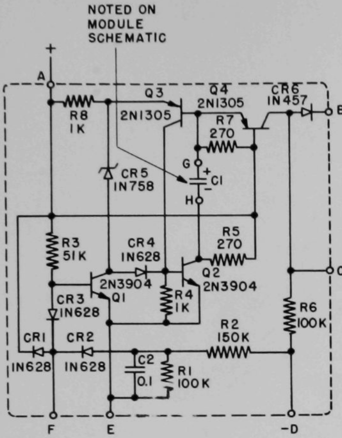


Fig. A.3. CRM Board IHS-130

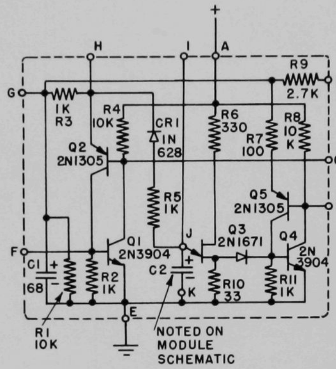
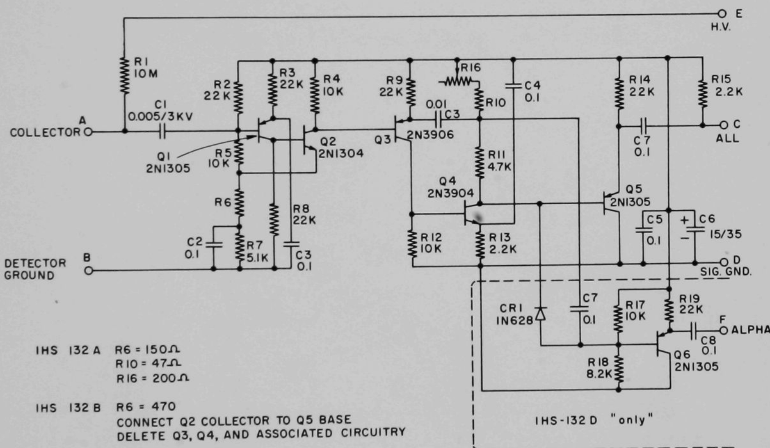


Fig. A.4. Alarm and Timer Board IHS-131



IHS 132 A R6 = 150Ω
R10 = 47Ω
R16 = 200Ω

IHS 132 B R6 = 470
CONNECT Q2 COLLECTOR TO Q5 BASE
DELETE Q3, Q4, AND ASSOCIATED CIRCUITRY

IHS 132 C R6 = 470Ω
R10 = 220Ω
R16 = 0

IHS 132 D R6 = 470Ω
R10 = 47Ω
R16 = 200Ω WITH Q6 AND ASSOCIATED CIRCUITRY

Fig. A.5. Pulse Preamplifier IHS-132

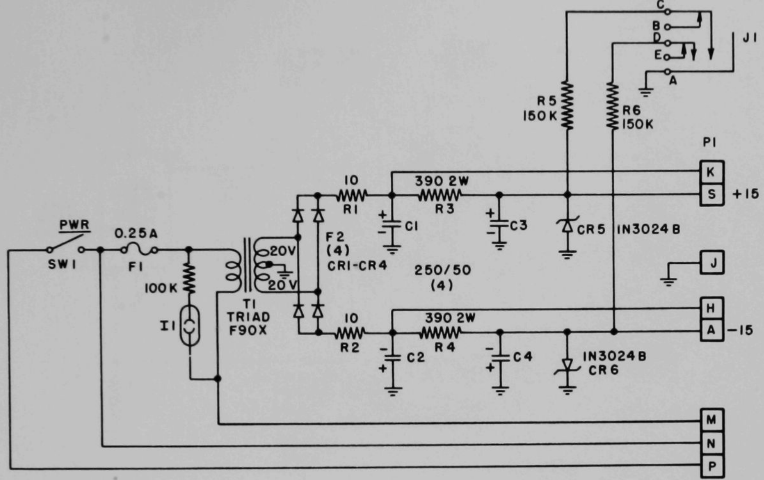


Fig. A.6. L. V. Power Supply Module IHS-133

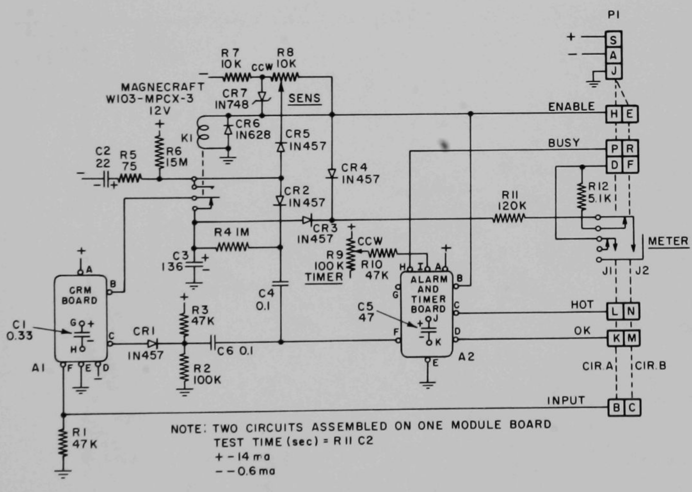


Fig. A.7. Differential-rise Alarm Module IHS-134

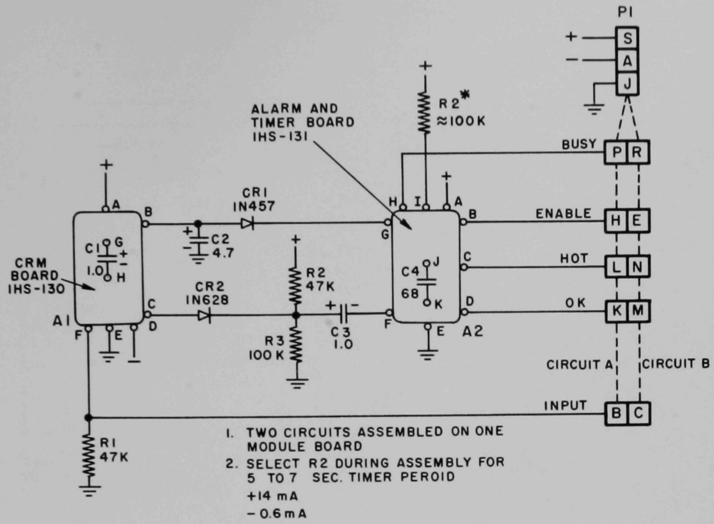


Fig. A.8. High-level Alarm Module IHS-135

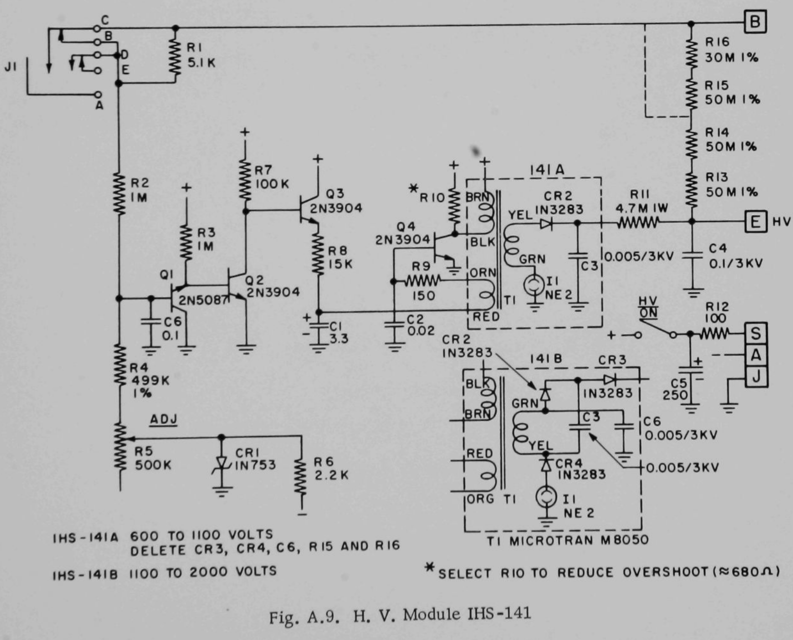


Fig. A.9. H. V. Module IHS-141

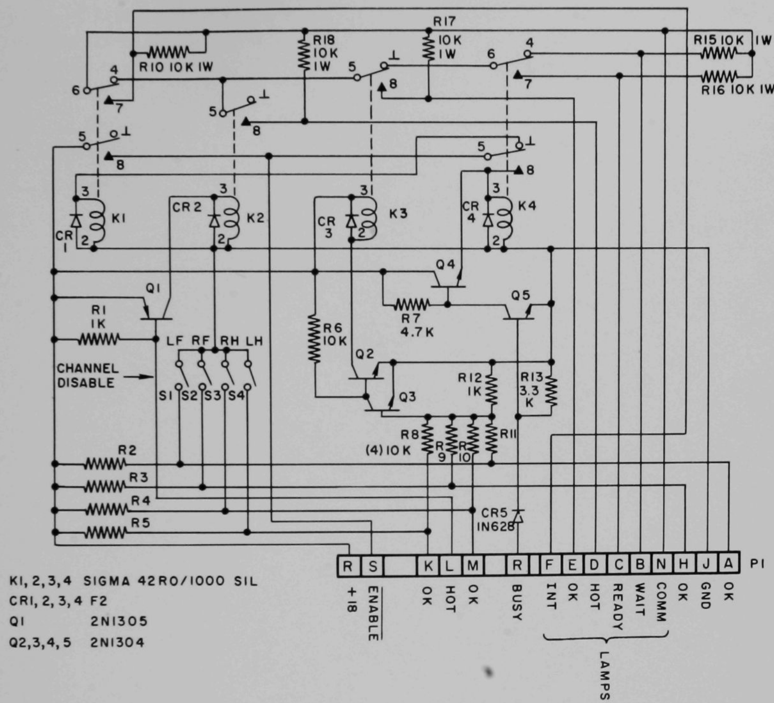


Fig. A.10. Lamp Logic Module IHS-143

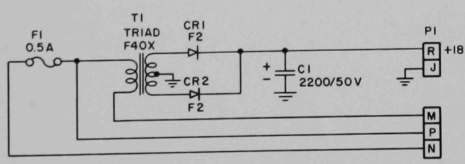


Fig. A.11. Lamp P. S. Module IHS-147

ACKNOWLEDGMENTS

I would like to thank William Stigberg for the fabrication and checkout of the prototype circuitry, the Radiation Measurement and Instrumentation Shop personnel (Joe Ello, Supervisor) for fabrication of the original monitors, and Frank Marchetti for field evaluation.